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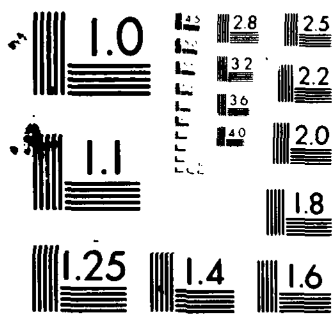

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INSTITUTIONAL SUPPORT OF WATER RESOURCE MODELS

by

JOHN C. PETERS

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Water Resources Support Center
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Solutions to human and institutional problems that inhibit effective development and use of water resource computer models are identified. Support of water resource models is treated under the topics of quality contorl, technology transfer, model improvement and maintenance, and education of managers/decision makers. A main theses is that effective model support is best achieved by means of centralized organizational units that are designed to perform a wide range of support activities that include model evaluation and enhancement

(continued)

20. ABSTRACTS (Continued)

preparation of documentation, user assistance, maintenance, the conducting of training courses and seminars, and project applications.

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INSTITUTIONAL SUPPORT OF WATER RESOURCE MODELS[1]

by

John C. Peters[2]

INTRODUCTION

The purpose of this paper is to identify solutions to human and institutional problems that inhibit effective development and use of water resource computer models. A model may be regarded as a powerful tool for analyzing alternative solutions to water resource problems. Application of models enables analysis of a wider range of solutions, and a more detailed analysis of individual solutions, than would otherwise be possible. Indeed a rational analysis of some of today's complex water resource problems would be virtually impossible without models.

While many illustrations of successful model application could be cited, the focus herein is on problems associated with model development and use that impact on both the quality of solutions to water resource problems and the efficiency (cost effectiveness) with which the solutions are obtained. Some recurrent problems are as follows:

(1) Models are not user-oriented; that is, excessive amounts of manpower resources are required to prepare input for, and operate, the models.

(2) Documentation on how to use the models is deficient or nonexistent; excessive amounts of manpower resources are required to learn how to use the models.

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1. Prepared for the U.S. Congress, Office of Technology Assessment Report on "Freshwater Resources Management, Planning and Policy; An Assessment of Models and Predictive Methods."

2. Hydraulic Engineer, The Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California, May 1980.

(3) Models are not readily transportable from one computer system to another; excessive manpower and computer resources are required to adapt a model for use on the computer system available to the model user.

(4) Models are faulty and produce erroneous results.

(5) Models are inefficient; excessive amounts of computer resources are required to operate the models.

(6) Inferior models are used because of a lack of awareness of the availability of more suitable models.

(7) Models are misapplied due to an inaccurate assessment of the problem to be solved or a lack of understanding of model capabilities and limitations.

(8) Erroneous results of model applications are not detected because of inadequate checking and verification of model output.

(9) Training in model application is not available; excessive manpower and computer resources are required to learn how to use the models.

(10) Assistance in model application is not available; excessive manpower and computer resources are required to learn how to use the models.

(11) Models, once developed, are not subsequently maintained; that is, there is no mechanism for generating model improvements or error corrections, or for disseminating them to model users. This results in faulty or inefficient applications of models.

(12) Models are developed to solve inconsequential problems or to utilize data that is seldom or never available.

(13) The role of models in solving water resource problems is not understood by managers/decision-makers, which results in misapplication of models and inferior problem solutions.

Numerous examples could be cited to illustrate each of the above problems. When viewed from a national perspective, the consequences of the problems are substantial with respect to reduced quality of solutions to water resource problems, and higher costs for obtaining solutions. Possible solutions to the problems listed above are addressed subsequently in this paper under the following four topics:

- Quality Control
- Technology Transfer
- Model Improvement and Maintenance
- Education of Managers/Decision Makers

Solutions to problems (1) through (5) will be addressed under the topic of Quality Control, problems (6) - (10) under Technology Transfer, problem (11) under Model Improvement and Maintenance and problems (12) and (13) under Education of Managers/Decision-Makers. The viewpoints expressed in this paper are based, for the most part, on actual experiences of the Hydrologic Engineering Center[1] (HEC) of the U.S. Army Corps of Engineers in addressing these problems during the last sixteen years.

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1. The Hydrologic Engineering Center was established in 1964 to provide research, consulting and training services in the disciplines of hydrologic engineering and water resource planning to the 52 district and division offices of the Corps of Engineers. Activities of the Center are focused to a major extent on developing, applying, servicing and teaching the use of water resource models.

QUALITY CONTROL

As indicated previously, a water resource model may be viewed as a tool for facilitating the determination of solutions to water resource problems. Such tools are very sophisticated in that they are composed of numerous interrelated sets of extensive, complex computation sequences. Newly developed models invariably contain errors (bugs, in computer vernacular) that cause the model to produce erroneous results. Model reliability is pursued with comprehensive and systematic programs of debugging, testing and verification. Such programs are time consuming and expensive, especially if substantial amounts of data (e.g. physical characteristics of watersheds, streamflow measurements, groundwater levels, etc.) must be collected for model verification.

A common practice in model testing is to make a preliminary version of a model available to selected model users with the understanding that the model is in the testing stage and that the users will notify the model developer of malfunctions. This provides a means to have a model used in a variety of applications, some of which would not have been anticipated by the model developer.

Even the most carefully designed and executed testing program will not assure perfect model reliability, because of the complex nature of models and the unforeseen characteristics of individual applications. Generally the most reliable models are those that have been widely used for a period of several years. An essential requirement for increasing the reliability of a model is to have a systematic means for making changes to the model,

and for disseminating the changes to model users. These activities will be addressed subsequently under Model Improvement and Maintenance.

Factors other than computational reliability that contribute to the quality of a model include computational efficiency, ease of use, model transportability and the adequacy of documentation. Computational efficiency pertains to computer costs associated with operating a model. Good computational efficiency is generally achieved by careful design of the model to enable efficient transfer of information within the model and by application of state-of-the-art procedures for manipulating and solving equations.

The ease with which a model can be used is substantially dependent on the design of the input and output structures of the model. A 'user-oriented' model has an input structure that enables the user to input required information (data) with a minimum of effort. The model checks the data for completeness and reasonableness, and transforms it into formats required for subsequent processing. The output structure is designed so that the user can select the level of detail and general arrangement of model output. A user-oriented model provides diagnostic information in the case of an abortive application, and furnishes warnings when model-generated information exceeds reasonable bounds.

Model transportability refers to the ease with which models can be transferred from one computer system to another. Characteristics of computer systems vary substantially from one manufacturer to another. A model designed to take full advantage of the various features of a particular computer system, for example for storing information or solving equations, may have to undergo major restructuring for use on another computer system.

Costs associated with restructuring and subsequent testing can be substantial. If a model is intended for widespread use on a number of different computer systems, the model should be designed for transportability by avoiding the use of system-dependent features of any particular computer system. Designing for transportability requires knowledge of the essential characteristics of a variety of computer systems. Such knowledge is difficult to acquire and is not widespread among model developers; that is, most model developers are very knowledgeable about the computer system that they use, but not about other systems.

The last item included herein under 'quality control' is model documentation. This item could also be included under 'technology transfer', however it is considered more appropriate to associate documentation closely with overall model quality, because without adequate documentation, application of a model will at best be grossly inefficient. At worst, the model can be misapplied in such a fashion that erroneous results are not detected by the user.

Consider this analogy. Suppose that a sophisticated lathe has been acquired for specialized machining tasks. It would certainly be prudent to become thoroughly familiar with the Users Instructions for the lathe prior to operating it. Presumably a trial and error approach could be used to figure out how the lathe works. But such an approach would be time consuming and expensive, and the full capabilities (and limitations) of the lathe may never be discovered.

A water resource model can be many times more complex than a lathe, yet the Users Instructions (model documentation) are typically so brief or poorly written that the model user must resort to a trial and error approach to learn how to use the model.

There are several reasons for the typical lack, or poor quality, of model documentation. Preparation of good documentation requires strong skills in written communication, and is an exacting, time-consuming task. The model developer, who may be the only person with the requisite knowledge of the model, may lack the skills, time or inclination to prepare proper documentation. Although rewards for model development are often significant, especially in an academic environment, there are generally few rewards for preparation of good quality model documentation. Funds are often overspent on the model-development part of a contract, leaving limited funds for the documentation phase.

Model quality, then, is multi-faceted and encompasses first and foremost, model reliability, but also includes elements such as computational efficiency, ease of use, transportability and documentation. Production of a model of high quality in all of these areas requires a large investment of specialized skills and should be reserved for models that will receive widespread use over a significant period of time. The need for such investments should be established by decision makers (managers) and others who have day-to-day responsibility for selecting techniques to be applied in solving water resource problems.

The quality of models can be regulated and monitored to a certain extent through specification of standards for model development and documentation, and by establishing review processes. For example, the U.S. Army Corps of Engineers established guidance and standards for models that are incorporated in the Corps' Engineering Computer Programs Library.[1] The stated objectives of the standards are to assure that models distributed through the Library are:

a. Immediately usable, broad in scope, easy to modify.

b. Consistent with accepted engineering principles and practices.

c. Uniformly and well documented.

d. Readily understandable by others and easy to set up and apply.

The standards specify the programming language to be used and suggest specific programming practices that will enhance program usability. Detailed guidelines are provided for preparation of model documentation. Models that are incorporated in the Library are placed in one of three categories, depending on the nature of the model and the level of review it has received. For example, a model in the highest category will have been designed for Corps-wide application and will have received independent review, and approval by the Corps' Office of the Chief of Engineers.

1. Engineering Computer Programs Library - Standards and Documentation, Engineer Technical Letter No. 1110-1-45, U.S. Army Corps of Engineers, 9 February 1971.

TECHNOLOGY TRANSFER

Technology transfer is intended herein to deal with the passing of information between model developer and model user, and in particular with procedures for fostering proficiency in model application. Mechanisms for technology transfer include dissemination of information regarding model availability, publication of model documentation, provision of user-assistance services and training of model users.

Dissemination of information regarding model availability is important for several reasons:

(1) The need for a model may be met, or partially met, with one that already exists - thus eliminating or reducing the necessity for costly model development.

(2) Awareness of the availability of models that are superior to ones presently in use may lead to improved model utilization.

(3) Interaction between model developers is fostered.

Existing sources of information on model availability include technical journals, catalogues produced by various government agencies and research entities, and user organizations such as the Storm Water Management Model users group or Civil Engineering Program Applications, Inc. (CEPA).

The need for model documentation is discussed in the preceding section on Quality Control. Model documentation should be viewed as encompassing far more than a set of instructions on how to prepare input for a model. A model user should have access to the following types of information:

(1) A comprehensive statement of the purpose, capabilities and limitations of the model.

(2) A detailed exposition of the theoretical basis for the model.

(3) A summary of the nature and extent of testing and verification of the model.

(4) Instructions on model usage.

(5) A description of model output.

(6) Examples of input and output.

(7) Case studies involving model applications.

In addition, written information should be provided on the internal organization and structure of the model to facilitate the making of modifications. Modifications may be required to install the model on a computer system, to correct errors or to augment capabilities.

User assistance is a critical element of technology transfer - critical in the sense that if it is not available, use of a model will probably be greatly inhibited and may cease altogether. User assistance requires ready access, generally by telephone, to a person who is thoroughly familiar with a model. Assistance may consist of providing information on the current status of a new model, advice on model applicability, guidance on input preparation or output interpretation, or help in locating the cause of abortive model executions. Persons providing the assistance receive valuable feedback on model applications which can be shared with other model users and can provide a basis for future model improvements.

For some model applications, particularly those that involve models that are extraordinarily complex, the most effective user assistance may involve "tutored application" in which model specialists and model users work together in applying the model to the users' specific problem. The specialists and users both gain from this experience, and the users are then equipped to tackle subsequent problems on their own, or at least with a much-reduced level of assistance.

Generally the single most effective mechanism for facilitating proper and efficient use of water resource models is the training course. A typical training course is two to ten days in duration and provides instruction in model applicability, the theoretical basis for a model, input preparation and output analysis. Case studies illustrating model applications are often included and there is generally an opportunity for discussion of problems brought by participants. Also many courses provide for hands-on use of models during problem-solving sessions. Such sessions are frequently regarded by participants as the most valuable component of a course.

Training courses on selected models are presently offered by several government agencies, by a number of universities and occasionally by private engineering firms. Attendance at government-sponsored training courses is in most cases limited to government personnel, whereas training courses sponsored by universities and private firms are open to the public. University offerings have increased significantly in recent years, which presumably reflects a growing awareness of the demand for and value of such training.

An adjunct to training courses that is used by at least two government water resource agencies is the video tape lending library. Video tapes are made during training courses. The tapes and associated training materials are then made available for loan to the public. Although the use of video tapes is generally less valuable than participation in a training course, such use is simple and relatively inexpensive, and can be of substantial value when attendance at training courses is not feasible.

An illustration of successful technology transfer can be cited in conjunction with the water resource model HEC-2, which is used for calculating water surface profiles (i.e. depths of flowing water) in rivers. This type of model is used extensively in a variety of water resource analyses - a prime example being the technical studies associated with the federal flood insurance program. HEC-2 was first made available by the Hydrologic Engineering Center in 1969 after approximately five years of development and testing. Since that time, many minor revisions and several major revisions have been made to meet the changing needs of model users. Documentation includes a comprehensive Users Manual, a Programmers Manual and several supplementary reports and technical papers that deal with applications. User assistance is readily available from the Hydrologic Engineering Center. During calendar year 1980, eight training courses in use of HEC-2 are being sponsored. Sponsors include the Hydrologic Engineering Center, the Ministry of Natural Resources for the Province of Ontario, Canada and several universities in the United States and Canada.

The Hydrologic Engineering Center distributes approximately 300 copies of the HEC-2 model and 2000 Users Manuals per year. The present list of users includes 107 federal government offices, 107 state and local government offices, 93 universities, 424 private engineering firms and 116 foreign offices and universities. The HEC-2 Users Manual has been translated into other languages.

In contrast to the widespread usage of HEC-2 are the numerous situations where federally-sponsored university research results in the development of a potentially useful model that ultimately receives minimal or no usage by those engaged in solving water resource problems. The reason such models are not used is often directly related to poor (or non-existent) attempts at technology transfer. In many cases the developer does not have the resources, skills or perhaps inclination to foster technology transfer, and is soon engaged in another research project for developing another model that will not be used.

The practitioners - those engaged in solving water resource problems on a day-to-day basis - generally have resources to use only those models that are proven and well-supported. The practitioner typically has little time or perhaps inclination to search for better tools that are probably poorly documented and for which training and assistance are not available.

The gap between development of state-of-the-art models and application of such models for solving water resource problems is best bridged by organizational units that are designed specifically for that purpose. The staff of such units should include specialists who stay abreast of new

technology emanating from the research community <u>and</u> the current modeling needs of practitioners. Capabilities should exist to:

- disseminate information on model availability to practitioners, and on modeling needs to the model developers,
- test and evaluate models,
- enhance models to make them user-oriented and transportable,
- prepare documentation,
- provide user assistance,
- provide training,
- perform maintenance activities, and
- provide guidance to model developers on the design of models for usability and transportability.

In order to insure that model specialists remain cognizant of the modeling needs of practitioners, project application of models should be part of the assigned responsibilities of an organizational unit for technology transfer. Federal agencies concerned with water resource management are logical candidates for establishing such units. However units should be designed and funded so that services can be utilized by virtually all segments of the professional community concerned with water resource management.

MODEL IMPROVEMENT AND MAINTENANCE

Most water resource models that are used on a day-to-day basis are dynamic in that they undergo continuous change. Changes are made to correct errors, increase computational efficiency, add new capability or modify input or output structures. An essential aspect of model improvement and maintenance is the process of implementing and testing such changes, and disseminating them for incorporation in existing copies of the model. Other aspects include the issuing of copies of the model to new users and the updating and disseminating of model documentation.

The life cycle of a complex water resource model has several stages. After initial development, a model typically has limited capability, contains bugs and may be inefficient. Following a comprehensive program of testing, verification and further development, which may include controlled usage by a select group of users who provide feedback to the developer, the model is fairly reliable and is at a state where it can be made available to practitioners. As use of a model grows, more errors are found and the need for enhancing the model's capabilities becomes readily apparent. The improving of a model's capabilities may continue for many years, in which case the model will periodically undergo complete revision with major additions to capability. Alternatively, after a period of usage the model may remain relatively unchanged, in which case use will eventually terminate when superior models become available.

Changes to models should be developed only by persons who have a comprehensive knowledge of the internal structure of the model. Whenever a

model is modified, it should be subjected to rigorous testing to insure that all components of the model remain sound. A systematic procedure should be established for informing users of model deficiencies as they are discovered and of measures required to correct the model. Model improvement and maintenance activities should be centralized for the following reasons:

(1) A centralized facility provides a focal point for receiving information on model deficiencies or on desired improvements.

(2) It is generally much more efficient to develop and test changes at a centralized facility and disseminate them, than it is for users to individually develop such changes.

(3) A centralized facility is a source from which up-to-date copies of a model can be obtained. This helps to reduce, if not eliminate, the proliferation of spurious model versions that contain poorly-tested modifications. Also consistency and credibility of model applications are enhanced when essentially identical copies of a well-maintained model are used.

An important aspect of model improvement and maintenance is the updating and dissemination of model documentation. As model capabilities change, the manuals describing how to use the model must be revised. This is often accomplished with user manual supplements in the case of minor changes. However when a model undergoes major revision, completely new documentation is generally required.

Consider the following description of model improvement and maintenance services provided by the Hydrologic Engineering Center as an illustration of the mechanics of providing such services. When a request for a model is received, the requestor is sent a magnetic tape containing a copy of the model and a set of standard test data with which to verify proper installation of the model. A copy of documentation is supplied with the tape. When the model is subsequently modified, the requestor will automatically receive detailed instructions on how to implement the model changes. Also notification will be sent when a revised version of the model and/or new model documentation become available. There is no direct charge for this service to requestors from federal government agencies. A nominal charge (generally $120 per tape) is made to all others to cover costs for materials and handling.

Model improvement and maintenance should be an integral part of an organizational unit concerned with technology transfer, the functions of which were discussed in the preceding section. The key to effective model improvement and maintenance, aside from the mechanics for model distribution, is the availability of highly qualified specialists who have or who acquire a comprehensive knowledge of the water resource models to be supported. It would probably be very difficult to attract and retain such a staff if model improvement and maintenance were their only task. It has been the experience of the Hydrologic Engineering Center that a highly qualified group of specialists can readily be retained if individual assignments include a suitable mix of tasks that include research, user assistance, project applications and teaching in addition to model improvement and maintenance.

Investments that are made in model development can be largely wasted if model improvement and maintenance support is not available to take over after initial development is completed. Unfortunately the need for such support has been overlooked to a great extent by those who invest in model development, perhaps because of a lack of awareness of the inevitable process of continual change that any well-used model will undergo.

EDUCATION OF MANAGERS/DECISION MAKERS

Managers are responsible for controlling the manner in which solutions to water resource problems are achieved. It is therefore important that they be well-informed with regard to both the role of models and of appropriate approaches to model utilization. Managers should be cognizant that:

(1) Models are only tools. When used properly, they can be a very valuable, often indispensable, aid for solving problems. But there is potential for misappropriate application.

(2) Models should be tailored to the problem, not the problem to the model. A clear understanding and definition of the problem is a crucial first step in problem solving.

(3) Models invariably have a distorted view of the real world. Care must be exercised to ascertain that the <u>essential</u> characteristics of the real world are being preserved in model application.

(4) Evaluation of the sensitivity of results to various assumptions about the character of the real world is an integral part of problem solving.

(5) Models can be faulty and can produce erroneous results. Rigorous verification (where possible) and review of model results should always be made to insure reasonable, consistent problem solutions.

Training courses and seminars are logical mechanisms for sensitizing managers to proper model utilization. Perhaps such courses are best geared to the overall approach to problem solving rather than to consideration of model usage as an end in itself. This will help to assure that the role of models is kept in proper perspective. Case studies illustrating appropriate, and also inappropriate, model usage would be a valuable component of such courses.

Organizational units for technology transfer should provide services that are geared specifically for meeting the needs of managers. In addition to conducting special seminars and workshops, this can include preparation of written guidance on proper model utilization. Also case studies that are written from the manager's point of view would be valuable, as would reports that provide succinct, concept-oriented summaries of the capabilities and limitations of models that are available for solving specific types of water resource problems.

The knowledge that model specialists have of model capabilities and of procedures for applying models is an important resource that should be available to managers. Advisory services provided by model specialists can help assure that models are used appropriately and can have a major impact on the manner in which a solution to a water resource problem is attained.

The knowledge that managers have of current water resource problems and needs is a unique and valuable resource that should be drawn upon by both those who develop models and those who invest in model development. Appropriate use of this resource would help to circumvent the developing of models for inconsequential problems, or models that require data (as input) that is seldom or never available. Organizational units for technology transfer should create forums that foster much needed communication between managers and those concerned with model development.

SUMMARY AND CONCLUSIONS

The initial development of a water resource model should be regarded as just one phase of an extensive process for enabling efficient and effective application of that model by practitioners. Lack of recognition of the necessity for the other phases of this model support process results in wasted investments and deprives practitioners of potentially valuable tools with which improved solutions to water resource problems could be obtained. Specific consequences of lack of support are listed in the introduction to this paper.

A number of aspects of the model support process have been described under the topics of quality control, technology transfer, model improvement and maintenance, and education of managers/decision makers. The support activities described are not hypothetical. Most are presently being practiced by the Hydrologic Engineering Center in support of water resource models used by the Corps of Engineers. The widespread and successful usage of models supported by the Hydrologic Engineering Center attests to the effectiveness of the support activities.

Substantial investments, in terms of dollars and skilled specialists, are required for effective model support. A main thesis of this paper is that such investments are best made in centralized organizational units that are designed to perform the whole array of support activities described herein; including model evaluation and enhancement, preparation of documentation, user assistance, maintenance, the conducting of training courses and seminars, etc. The organizational unit should also be involved in project applications so that model specialists acquire a firsthand knowledge of practical application of models. Support activities should be combined because there is significant overlap in the knowledge and skills required to perform them. Also the mix of functions provides a means for job enrichment for attracting and retaining a cadre of skilled specialists.

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